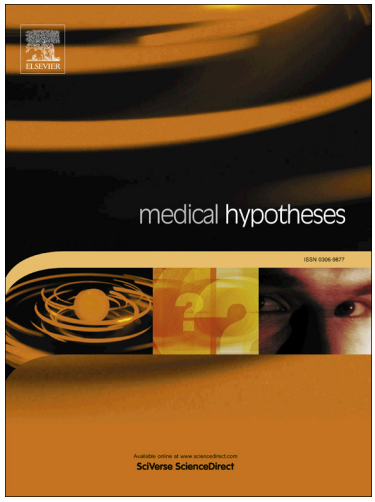
Paying the price for body evolution



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PAYING THE PRICE FOR BODY EVOLUTION.

The role of evolution in disorders of body representation.

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Abstract

Since its beginning, research about cognitive representation of our bodies has debated over multiple representations models. Furthermore, recent years have seen a rise in the study of body representation disorders and related impairments. However, why human beings manifest so many deficits is still a mystery. Considering human evolution, frontal brain regions are well known for their changes in dimensions and connections. Less known is that parietal and temporal lobes encountered similar changes. These areas, especially in the right hemisphere, are crucial for body representation. Our hypothesis is that evolution of these areas determined a more varied and widespread cross wiring between the temporal and parietal lobes, increasing their communication pathways and their reciprocal influence. As such, these connections could lead to an increased probability of interconnected body and emotional disorders in humans. The prediction of this hypothesis is that all body representation disorders have an associated emotional component and vice versa. Evidence supporting the interconnection between emotional and body representation disorders derives from psychiatric diseases such as eating disorders. This hypothesis opens up new directions to understand body representation and points towards innovative solutions for the clinical treatments of body representation/emotional impairments.

Introduction

We all share one feature. Independently form where we live, what kind of culture we belong to, and all the other variables one can think about, we have only one physical body. We can modify our body in terms of external appearance. It can become bigger or smaller by eating a lot of junk food or, on the contrary, tons of vegetables. It can be decorated by changing our skin colour through tanning beds or by adding nice jewellery. It can be loved or hated as sometimes happens in eating disorders, where the body is humiliated through food misuse. Finally, we can use it or not by being active sport players or lazy television watchers. In fringe cases, we can also exchange a part of our body with somebody else, like it happens for hand transplantations. However, we cannot change it completely as we change our dresses: we do not have an additional body, like a "seasonal body" for winter and for summer.

Nevertheless, since its beginning, research on the cognitive representation of our body has debated over multiple body representations. One example for all is the famous dichotomy between the body schema and the body image, also known as the dyadic model of body representation [1]. Starting from the Nineteenth Century, descriptions of how we represent our bodies have begun to distinguish an action related representation, which includes postural and sensory information, and a conscious representation related to emotions and semantic knowledge [2,3]. This separation of concepts resembles the division of labour between the action and perception streams, or the ventral and dorsal streams model [4]. On one hand, we have concepts that are more linked to the perceptual frame (body image, sense of ownership). On the other hand, body schema and sense of agency are relatives of the dorsal stream, focused on acting on the environment. More

recently, triadic models of body representation have been put forward to further define the body image concept, introducing a distinction between a body semantics and a body structural description, more concerned with the spatial localization of body parts [1]. Similarly, new developments of the concept of body schema have been proposed, involving a different role for somatosensory information [5].

Independently from the theoretical reference assumed when studying body representation, recent years have seen a rise in the study of body representation disorders. The plethora of body representation impairments ranges from brain lesion-related deficits (such as somatoparaphrenia) [6] to psychiatric conditions involving a disturbance in the representation of the body (such as eating disorders) [7]. Especially these last conditions have attracted the attention of neuroscience, with the development of new paradigms aimed at clarifying the role of brain substrates in these diseases, once thought as psychological reactions to traumatic events without brain-based components.

It is puzzling surveying how many conditions in human beings involve body representation disturbances in association with emotional impairments, especially if they imply a bidirectional route for symptoms (i.e. Patients with eating disorders showing a modified body image even when they are in recovery, possibly as a consequence of the prolonged emotional impact on their perception; [7]). Could it be a coincidence or is there a causal role associating these two impairments? The hypothesis proposed here is that pathologies of body representation in humans might originate from the wiring of two precise brain areas: the parietal lobe and the temporal lobe. It is of uttermost importance to understand if complex conditions involving emotional components directed towards the body might involve also a dysfunctional representation of the body itself. This would open up the opportunity to develop new treatments or to tailor existing treatments to help

patients restructure their image of the self (such as transcranial Direct Current Stimulation (tDCS) protocols for stroke) [8].

The Hypothesis/Theory

It is well known that brain regions have changed in terms of both dimension and connections through the evolution of humanity. The most known change from the animal brain to that of human beings is described for the frontal lobes. These areas have encountered a drastic evolution to accommodate language and executive functions abilities that are typical of humans [9–11].

It is less known that also our parietal lobe encountered similar drastic changes. Particularly, the inferior region of the parietal lobe expanded (Inferior Parietal Lobe or IPL): area PG in Von Economo maps or area 39 in Broadmann's classification are not found in the monkey brain [12]. These cortical regions are devoted to polymodal associative processes that involve responding to both visual and somatosensory stimuli [13]. Secondly, another area developed new properties: the superior temporal sulcus (STS, area 22 in Broadmann's classification). One study reports STS asymmetries in the human brain, even in the foetal period, and these asymmetries are not described in monkeys [14]. Not by chance, this area also has polymodal visual and somatosensory properties [15]. Area 22 in Broadmann's classification also expanded and auditory properties increased. These expansions took place especially in the right hemisphere of the human brain [15].

Not by chance, the parietal and temporal lobes in the right hemisphere are the brain areas for body representation, and they are dysfunctional in all disorders that involve this component [16–18]. The idea that the evolution of these areas is responsible for body representation disorders shall not be taken as a localization of a disease. Rather, evolution

and expansion of these areas determined a more varied and widespread cross wiring between the temporal and parietal lobes, increasing their communication pathways and increasing their reciprocal influence [19] (figure 1). Exactly the development of these connections could lead to an increase probability of interconnected body and emotional disorders in humans, rather than a focal change in a unique brain substrate.

[Figure 1 here]

Theories that support connection between body representation and emotions take into account a "bottom-up" direction, referring to the so called "material me" [20] instead of a holistic body representation. In 2002, Craig suggests that interoceptive sensations are the basis to build a subjective sensation and emotions [20]. Similarly, Damasio et al. (2000) [21] propose that emotions arise from an evolutionary mechanism functional for survival and implicated in maintaining homeostasis. Further emotions depend on structures related to the representation of the physical body according to these authors. Taken together, this evidence supports a functional relation between the physical body state representation and emotions. However, it does not clarify what happens at the "higher" level of body representation. It is plausible to think that, at this level, not only basilar bottom-up mechanism are implicated (i.e. interoceptive sensations) but also higher cognitive processes (i.e. cognitive amplification of interoceptive signals). The connection between emotions and body representation could be present in humans thanks to an increased connectivity between the right parietal and temporal lobes (figure 2).

[Figure 2 here]

This idea is also highly related to that of anatomical proximity or proximal contiguity. The concept of proximal contiguity is widely discussed in the (debated) "The Tell-Tale Brain: A Neuroscientist's Quest for What Makes Us Human" book by Ramachandran (Chapter 3) [22]. While the scientific controversy on oversimplification that the book

might suffer is out of matter here, the concept and its description have an enormous value if one wants to understand the above-mentioned matters on body representation and evolution. Anomalous cross – wirings between brain areas have been suggested for some neurological conditions. This is the case of synaesthesia [23]. In this condition, individuals experience sensations in one modality when a second modality is stimulated. For instance, a person can experience a specific colour every time she encounters a grapheme (i.e., the letter "b" may be represented in association with the colour green). The anatomical proximity can explain synaesthesia as colour and visual grapheme areas in the brain are both in the fusiform gyrus and well connected to each other [24]. Anatomical proximity has also been called into cause for Capgras delusion, a condition in which the individual is convinced that his relatives have been substituted by an impostor [24]. Impairments in this condition spread over several tasks related to face perception and not only confined to the recognition of a familiar face [25,26]. Again, the neural basis of these tasks involve areas that are widely intercommunicating [24]. Paraphrasing a sentence: "Can it be a coincidence that the most common form of body representation disorder involves an emotional component – the reverse being also true - and the brain areas corresponding to these are right next to each other [and highly connected]?" (Modified from [23]).

In summary, it appears more than plausible that without the evolution of our fine graded motor and emotional abilities, psychopathological conditions related to body representation would have never existed. These conditions could be the price we pay for being able to understand complex social situations and for being able to sew small things. As Peter Brugger noticed in his 2012 paper "Species have evolved to survive in all manner of barren and inhospitable environments and those that did survive have all reached a degree of specialisation that makes them unique in some way or another" (pag.

357) [27]. Our evolution made us unique as well as other animals, and, as well as them, we pay the price of this uniqueness.

Importantly, psychopathological conditions related to body representation affect only part of the population, and not every human being. However, the more time passes the more different subcategories emerge and new conditions are identified. While it is true that they might simply have been underestimated, there is no experimental proof they already existed as they manifest today. In any case, these complex conditions have been proven impossible to study unless all accounts, biological, psychological and social, are considered. This reasoning applies equally to well-known body representation disorders such as anorexia nervosa, bulimia, binge eating and eating disorders in general as well as to some less known conditions. Somatoparaphrenia, for instance, involves a component of ownership but also an emotional one [28]. Body Integrity Identity Disorder is characterized by an overwhelming repulsion of the actual body representation, so deeply rooted to alter the entire individual's emotional life [29]. All these conditions can be understood in terms of a profound dysfunctionality in the networks related to both body representation and emotional processing. This is exactly the network that encompasses the parietal and the temporal lobe.

Evaluation of the hypothesis

The prediction of this hypothesis is that all body representation disorders have an associated emotional component. On the other hand, the reverse should also be true: all emotional disorders should have associated body representation impairments.

Evidence derives, on one hand, from psychiatric diseases and, on the other hand, from neuropsychological studies. However, not all evidence is so clearly supportive mainly because some studies considered only one process at time (emotion or body representation) and others explored the link between emotions and body representation

focusing on interoceptive signals and how patients interpret them without considering the higher processes related to the temporo-parietal cortex (see table 1).

[Table 1 here].

Consequences of the hypothesis and discussion

Human evolution lead to huge changes in the brain wiring. While development of the frontal lobes has attracted a lot of attention from neuroscience given its link with language advancements [9–11], much less attention has been devoted to the massive rewiring of the inferior region of IPL and of STS. These areas do not have immediate homologous in the monkey brain [12,14] but they are crucial for human body representation [16–18]. Further, these same areas are impaired not only in neuropsychological disorders involving the body [37,40], but also in psychiatric conditions such as eating disorders and in personality disorders [33,48].

The hypothesis proposed here is that the link between emotions and body representation found in all these conditions is a consequence of the evolution of parietal and temporal areas that has characterized human beings compared to other species. This widespread cross wiring increases the probability of joint disturbances of two functions that can be considered as anatomically proximal or contiguous [24]. Of relevance, this would mean that not only a "bottom-up" direction of influences [20,21] should be taken into account, but also "higher" levels of processing of both body representation and emotions.

From a theoretical perspective, the current hypothesis opens new directions of thought for body representation, pointing towards the need to reason and plan studies in a holistic fashion. In some ways, the aim is to exceed the current debate between dyadic and triadic models [1]. The body image and the body schema would not need any more to be seen as representations, but rather they would better fit as *components* of a wider representation driven by the communication between highly and tightly wired brain areas.

At a first look, this theory could be unsuitable from a research perspective. Considering one process at time allows to perform controlled experiments and to avoid the influence or bias from confounding variables. However, unless the results from the different experiments are integrated in a common theory, the phenomenon cannot be explained by means of a fragmented approach. Occam's razor (or Ockham's razor or lex parsimoniae) is a principle used in logic that states that the hypothesis with the fewest assumptions should be selected among competing ones [49]. If this principle is applied to the study of body representation, there is no hypothesis with few assumptions, just a lot of assumptions separating the diverse processes that human beings can undergo when using their bodies. Moreover, there is no clear definition available for some of the components, such as the body image, and emotional aspects of body representation are ill defined problems and difficult to explore [1]. A unique theoretical frame integrating all the assumptions on body representation and emotions is still lacking, but this should not be considered as an experimental limitation impossible to overcome.

From an experimental perspective, our hypothesis points towards a simple but efficient solution. Future experiments could take into account the relation between different processes, adding emotional measurements (such as affective batteries or classic interoceptive measurements) when performing classic body representation experiments. Furthermore, such an approach could also lead to comparative studies: interoceptive measurements are suitable for animals as well as humans [50,51]. If the hypothesis is true, experiments should be able to highlight differences between representations in humans and animals that are not only linked to anatomical differences (i.e. the diverse hand properties in a man versus a monkey and the associated differences in grasping kinematics) but also to functional wiring of body and emotional areas. Similarly, differences should emerge also in relation to sensitivity – or facilitation processes – if the

human body representation has stronger connections with emotional areas than the animal one.

More debatable is the lateralisation of the hypothesized evolutionary changes and, consequently, the lateralisation of the body representation. It is hypothesized that mainly the right side of the brain was involved in those changes, as reported by neuropsychological disorders previously reviewed [40,52]. Nevertheless, some authors showed different phenomena. For instance, some disturbances are characterized by left hemisphere lesions as well. In autotopoagnosia patients make errors when asked to name or point to different body parts on their self or on the others [53,54]. Gerstmann syndrome sees patients manifesting left-right disorientation and finger agnosia [55]. Apraxia, in which the correct movement is not performed [56]. In none of that, emotional impairments are reported yet. However, this does not mean that impairments are not presents. Experiments could be able to highlight differences (if any) between processes implicated in right-hemisphere related pathologies and left-hemisphere related ones, to shed light on the lateralization debate. The left hemisphere and its related pathologies could be interpreted as the result of a loss of communication between the lexical-semantic domain, related but not coincided with the body representation processes [28].

Considering the clinical side of such a hypothesis, it appears that the time has come to consider more widely symptoms in case of right brain damages. Hence, the need to explore both body representation and emotions in the clinical evaluation process and the related need to adopt or to develop neuropsychological assessment batteries in cases of right temporo and parietal damages. This statement is strictly related to the possibility to adopt new rehabilitation paradigms that might take into account the relation between body representation and emotions and that are not focused on body representation neuropsychological features only. For instance, therapies for somatoparaphrenia could

include stimulation of brain areas with techniques such as tDCS [57]. This kind of technique allows to modulate an entire circuit of the brain and as such could boost body areas (parietal ones) while diminishing the control of emotional areas (temporal ones) that could be the cause of a release of "emotional disownership" towards part of the body (figure 3).

[Figure 3 here]

Importantly this technique has already proven effective on other similar symptoms such as anosognosia [8]. This patient, treated with tDCS, also showed an amelioration of mood, as observed by the experimenters. This is unlikely to be a chance effect and sounds promising for future applications. Similarly, the "circuit approach" could benefit other pathologies involving the body and emotional reaction, such as Body Integrity Identity Disorder and eating disorders. Several treatments are available for eating disorders (e.g. Cognitive Behavioural Therapy-CBT, Dialectical Behaviour Therapy-DBT, Cognitive Remediation Therapy-CRT) [58] but all of them are focused on the behavioural dysfunctions and emotional feelings, with only marginal consideration of the neural basis. In the light of the present hypothesis, alternative forms of treatment should be suitable. If connections between body representation and emotions, even in neural terms, are taken into account, classical rehabilitation methods used in neuropsychology could be implemented also for these conditions. This is the case of Virtual Reality (VR). In fact, VR treatments have been recently developed for eating disorders and, not by chance, the mechanism proposed to be behind them is exactly an update of a system involving also spatial (so, body related) coordinates [59].

In summary, a closer look at the evolution of body and emotional related areas provides a clear suggestion on the shift of paradigm needed to be able to understand impairments

that possibly are the price we pay for being able to be social and emphatic human beings that can grasp a sewing needle.

Conflict of interest statement: The authors declare that there is no conflict of interest.

References

[1] De Vignemont F. Body schema and body image-Pros and cons. Neuropsychologia 2010;48:669–80. doi:10.1016/j.neuropsychologia.2009.09.022.

[2] Paillard J. Le corps situé et le corps identifié. Rev Méd Suisse Rom 1980;100:129, 141.

[3] Gallagher S. How the body shapes the mind. Oxford Clarendon Press 2005:173–8.

[4] Milner, A. D., & Goodale MA. The visual brain in action. Oxford: 1995.

[5] Longo MR, Azañón E, Haggard P. More than skin deep: body representation beyond primary somatosensory cortex. Neuropsychologia 2010;48:655–68. doi:10.1016/j.neuropsychologia.2009.08.022.

[6] Vallar G, Ronchi R. Somatoparaphrenia: a body delusion. A review of the neuropsychological literature. Exp Brain Res 2009;192:533–51. doi:10.1007/s00221-008-1562-y.

[7] Eshkevari E, Rieger E, Longo MR, Haggard P, Treasure J. Persistent body image disturbance following recovery from eating disorders. Int J Eat Disord 2014;47:400–9. doi:10.1002/eat.22219.

[8] Gandola M, Sedda A, Manera M, Pingue V, Salvato G, Spitoni GF, et al. Selective improvement of anosognosia for hemiplegia during transcranial direct current stimulation: a case report. Cortex 2014;61:107–19. doi:10.1016/j.cortex.2014.08.007.

[9] Spocter MA, Hopkins WD, Garrison AR, Bauernfeind AL, Stimpson CD, Hof PR, et al. Wernicke's area homologue in chimpanzees (Pan troglodytes) and its relation to the appearance of modern human language. Proc Biol Sci 2010;277:2165–74. doi:10.1098/rspb.2010.0011.

[10] Flinker A, Korzeniewska A, Shestyuk AY, Franaszczuk PJ, Dronkers NF, Knight RT, et al. Redefining the role of Broca's area in speech. Proc Natl Acad Sci U S A 2015;112:2871–5. doi:10.1073/pnas.1414491112.

[11] Sherwood CC, Broadfield DC, Holloway RL, Gannon PJ, Hof PR. Variability of Broca's area homologue in African great apes: implications for language evolution. Anat Rec A Discov Mol Cell Evol Biol 2003;271:276–85. doi:10.1002/ar.a.10046.

[12] Aversi-ferreira TA, Ferreira M, Araújo P De. History , citoarchitecture and neurophysiology of human and non human primates ' parietal lobe 2010;4:173–80.

[13] Kolb, B., & Whishaw IQ. Fundamentals of human neuropsychology. Chapter 14, The parietal lobes,. 2009.

[14] Leroy F, Cai Q, Bogart SL, Dubois J, Coulon O, Monzalvo K, et al. New human-specific brain landmark: the depth asymmetry of superior temporal sulcus. Proc Natl Acad Sci U S A 2015;112:1208–13. doi:10.1073/pnas.1412389112.

[15] Kosslyn SM, Andersen RA. Frontiers in Cognitive Neuroscience. MIT Press; 1995.

[16] Blanke O, Arzy S. The out-of-body experience: disturbed self-processing at the temporo-parietal junction. Neuroscientist 2005;11:16–24. doi:10.1177/1073858404270885.

[17] Cazzato V, Mian E, Serino A, Mele S, Urgesi C. Distinct contributions of extrastriate body area and temporoparietal junction in perceiving one's own and others' body. Cogn Affect Behav Neurosci 2015;15:211–28. doi:10.3758/s13415-014-0312-9.

[18] Ionta S, Martuzzi R, Salomon R, Blanke O. The brain network reflecting bodily self-consciousness: a functional connectivity study. Soc Cogn Affect Neurosci 2014;9:1904–13. doi:10.1093/scan/nst185.

[19] Sherwood CC, Subiaul F, Zawidzki TW. A natural history of the human mind: tracing evolutionary changes in brain and cognition. J Anat 2008;212:426–54. doi:10.1111/j.1469-7580.2008.00868.x.

[20] Craig a. D. How do you feel? Interoception: the sense of the physiological condition of the body. Nat Rev Neurosci 2002;3:655–66. doi:10.1038/nrn894.

[21] Damasio a R, Grabowski TJ, Bechara a, Damasio H, Ponto LL, Parvizi J, et al. Subcortical and cortical brain activity during the feeling of self-generated emotions. Nat Neurosci 2000;3:1049–56. doi:10.1038/79871.

[22] Ramachandran VS. The tell-tale brain: A neuroscientist's quest for what makes us human. 2012.

[23] Ramachandran VS, Hubbard EM. Psychophysical investigations into the neural basis of synaesthesia. Proc Biol Sci 2001;268:979–83. doi:10.1098/rspb.2000.1576.

[24] Ramachandran VS. The Tell-Tale Brain: Unlocking the Mystery of Human Nature. London: n.d.

[25] Young AW, Reid I, Wright S, Hellawell DJ. Face-processing impairments and the Capgras delusion. Br J Psychiatry 1993;162:695–8.

[26] Ellis HD, de Pauw KW, Christodoulou GN, Papageorgiou L, Milne AB, Joseph AB. Responses to facial and non-facial stimuli presented tachistoscopically in either or both visual fields by patients with the Capgras delusion and paranoid schizophrenics. J Neurol Neurosurg Psychiatry 1993;56:215–9.

[27] Brugger P. The tell-tale brain: Unlocking the mystery of human nature. Cogn Neuropsychiatry 2012;17:351–8. doi:10.1080/13546805.2012.685295.

[28] Gandola M, Invernizzi P, Sedda A, Ferrè ER, Sterzi R, Sberna M, et al. An anatomical account of somatoparaphrenia. Cortex 2012;48:1165–78. doi:10.1016/j.cortex.2011.06.012.

[29] Sedda A, Bottini G. Apotemnophilia, body integrity identity disorder or xenomelia? Psychiatric and neurologic etiologies face each other. Neuropsychiatr Dis Treat 2014;10:1255–65. doi:10.2147/NDT.S53385.

[30] Mussgay L, Klinkenberg N, Rüddel H. Heart beat perception in patients with depressive, somatoform, and personality disorders. n.d.

[31] Müller LE, Schulz A, Andermann M, Gäbel A, Gescher DM, Spohn A, et al. Cortical Representation of Afferent Bodily Signals in Borderline Personality Disorder: Neural Correlates and Relationship to Emotional Dysregulation. JAMA Psychiatry 2015;72:1–10. doi:10.1001/jamapsychiatry.2015.1252.

[32] Pollatos O, Kurz AL, Albrecht J, Schreder T, Kleemann AM, Schöpf V, et al. Reduced perception of bodily signals in anorexia nervosa. Eat Behav 2008;9:381–8. doi:10.1016/j.eatbeh.2008.02.001.

[33] Mantovani A, Simeon D, Urban N, Bulow P, Allart A, Lisanby S. Temporo-parietal junction stimulation in the treatment of depersonalization disorder. Psychiatry Res 2011;186:138–40. doi:10.1016/j.psychres.2010.08.022.

[34] Terhaar J, Viola FC, Bär KJ, Debener S. Heartbeat evoked potentials mirror altered body perception in depressed patients. Clin Neurophysiol 2012;123:1950–7. doi:10.1016/j.clinph.2012.02.086.

[35] Hart N, McGowan J, Minati L, Critchley HD. Emotional regulation and bodily sensation: interoceptive awareness is intact in borderline personality disorder. J Pers Disord 2013;27:506–18. doi:10.1521/pedi_2012_26_049.

[36] Michal M, Reuchlein B, Adler J, Reiner I, Beutel ME, V??gele C, et al. Striking discrepancy of anomalous body experiences with normal interoceptive accuracy in depersonalization-derealization disorder. PLoS One 2014;9:15–21. doi:10.1371/journal.pone.0089823.

[37] Critchley M. Misoplegia, or hatred of hemiplegia. Mt Sinai J Med 41:82–7.

[38] McIntosh RD, Brodie EE, Beschin N, Robertson IH. Improving the clinical diagnosis of personal neglect: a reformulated comb and razor test. Cortex 2000;36:289–92.

[39] Lindell AB, Jalas MJ, Tenovuo O, Brunila T, Voeten MJM, Hämäläinen H. Clinical assessment of hemispatial neglect: evaluation of different measures and dimensions. Clin Neuropsychol 2007;21:479–97. doi:10.1080/13854040600630061.

[40] Heydrich L, Blanke O. Distinct illusory own-body perceptions caused by damage to posterior insula and extrastriate cortex. Brain 2013;136:790–803. doi:10.1093/brain/aws364.

[41] Pollak L, Klein C, Rafael S, Vera K, Rabey JM. Anxiety in the first attack of vertigo. Otolaryngol - Head Neck Surg 2003;128:829–34. doi:10.1016/S0194-5998(03)00454-6.

[42] Godemann F, Linden M, Neu P, Heipp E, Dörr P. A prospective study on the course of anxiety after vestibular neuronitis. J Psychosom Res 2004;56:351–4. doi:10.1016/S0022-3999(03)00079-5.

[43] Sang FYP, Jáuregui-Renaud K, Green D a, Bronstein a M, Gresty M a. Depersonalisation/derealisation symptoms in vestibular disease. J Neurol Neurosurg Psychiatry 2006;77:760–6. doi:10.1136/jnnp.2005.075473.

[44] Lopez C, Blanke O. The thalamocortical vestibular system in animals and humans. Brain Res Rev 2011;67:119–46. doi:10.1016/j.brainresrev.2010.12.002.

[45] Preuss N, Hasler G, Mast FW. Caloric vestibular stimulation modulates affective control and mood. Brain Stimul 2014;7:133–40. doi:10.1016/j.brs.2013.09.003.

[46] Bense S, Bartenstein P, Lochmann M, Schlindwein P, Brandt T, Dieterich M. Metabolic changes in vestibular and visual cortices in acute vestibular neuritis. Ann Neurol 2004;56:624–30. doi:10.1002/ana.20244.

[47] Lopez C. A neuroscientific account of how vestibular disorders impair bodily self-consciousness. Front Integr Neurosci 2013;7:91. doi:10.3389/fnint.2013.00091.

[48] Simeon D, Guralnik O, Hazlett EA, Spiegel-Cohen J, Hollander E, Buchsbaum MS. Feeling unreal: a PET study of depersonalization disorder. Am J Psychiatry 2000;157:1782–8. doi:10.1176/appi.ajp.157.11.1782.

[49] Myung IJ, Pitt MA. Applying Occam's razor in modeling cognition: A Bayesian approach. Psychon Bull Rev 1997;4:79–95. doi:10.3758/BF03210778.

[50] Grippo AJ, Carter CS, McNeal N, Chandler DL, Larocca MA, Bates SL, et al. 24-hour autonomic dysfunction and depressive behaviors in an animal model of social isolation: implications for the study of depression and cardiovascular disease. Psychosom Med 2011;73:59–66. doi:10.1097/PSY.0b013e31820019e4.

[51] Stiedl O, Jansen RF, Pieneman AW, Ogren SO, Meyer M. Assessing aversive emotional states through the heart in mice: implications for cardiovascular dysregulation in affective disorders. Neurosci Biobehav Rev 2009;33:181–90. doi:10.1016/j.neubiorev.2008.08.015.

[52] Feinberg TE, Venneri A. Somatoparaphrenia: Evolving theories and concepts. Cortex 2014;61:74–80. doi:10.1016/j.cortex.2014.07.004.

[53] Pick A. Störung der Orientierung am eigenen KÖrper. Psychol Forsch 1922;1:303–18. doi:10.1007/BF00410392.

[54] Semenza C, Goodglass H. Localization of body parts in brain injured subjects. Neuropsychologia 1985;23:161–75.

[55] Gerstmann J. Syndrome of finger agnosia, disorientation for right and left, agraphia and acalculia. Arch Neurol Psychiatry 1940;44:398. doi:10.1001/archneurpsyc.1940.02280080158009.

[56] Heilman KM, Rothi LJ, Valenstein E. Two forms of ideomotor apraxia. Neurology 1982;32:342–342. doi:10.1212/WNL.32.4.342.

[57] Been G, Ngo TT, Miller SM, Fitzgerald PB. The use of tDCS and CVS as methods of non-invasive brain stimulation. Brain Res Rev 2007;56:346–61. doi:10.1016/j.brainresrev.2007.08.001.

[58] Waller G. Recent advances in psychological therapies for eating disorders. F1000Research 2016;5. doi:10.12688/f1000research.7618.1.

[59] Riva G. Neuroscience and eating disorders: The allocentric lock hypothesis. Med Hypotheses 2012;78:254–7. doi:10.1016/j.mehy.2011.10.039.

Tables & Figures Caption

Table 1. Example of studies exploring Body Representation (BR) and Emotional processing (Emo) in two different fields (Psychiatric and Neuropsychological). In all studied disorders, an involvement of both components is known from the literature. However, as the table highlights, not all studies consider both components at the same time. The inclusion of the studies in the vestibular field is useful because it represents the most convincing evidence of the link between BR and Emo. Vestibular stimulation (e.g. Caloric Vestibular Stimulation-CVS or Galvanic Vestibular Stimulation-GVS) has a great influence on both body representation, due to the well documented overlap between vestibular and somatosensory networks [44]. Less known, vestibular stimulation influences also emotional processes [45]. As the vestibular system is not a primary area for emotional processing, interfering with it means changing the connection between temporo and parietal cortices [46,47]. These experiments are the only directly confirming the hypothesis proposed here, and they support the idea of changes in communication within the evolutionary hub of emotions and body representation. The third column describes the type of clinical populations. "Function explored" column indicates for each study which component has been taken into account (an X indicates if the function is explored).

Figure 1. Schematic representation of the expansion occurred during evolution of the connections between Parietal and Temporal lobe from both a functional (on the left) and an anatomical (on the right) point of view. The functional point of view refers to the processes related to the parietal and temporal lobe respectively. BR: body representation;

Emo: emotion. Bigger arrows represent greater wiring between areas and greater interaction between processes.

Figure 2. Interaction between emotion and body representation processes related to the self-perception from both a functional (on the left) and an anatomical (on the right) point of view. BR: body representation; Emo: emotion. The figure depicts the idea that the 2 processes are not separated, rather they are integrated in order to have a coherent sense of the self. Similarly, it is proposed that anatomically the intercommunication between areas generates a sense of the self, and not simply the activity in one or another area.

Figure 3. Treatment perspective based on the use of tDCS. The upper figure represents a possible placement of the anode electrode on the parietal lobe and the cathode electrode on the temporal lobe, in order to stimulate body compared to emotional related areas. This approach might benefit for instance eating disorder patients. The kind of montage to be chosen would depend on the kind of result that one would want to obtain. In general, as depicted by the bottom part of the figure, boosting one hub of the network would aim at rebalancing activations. BR: body representation; Emo: emotion.

Fig. 1

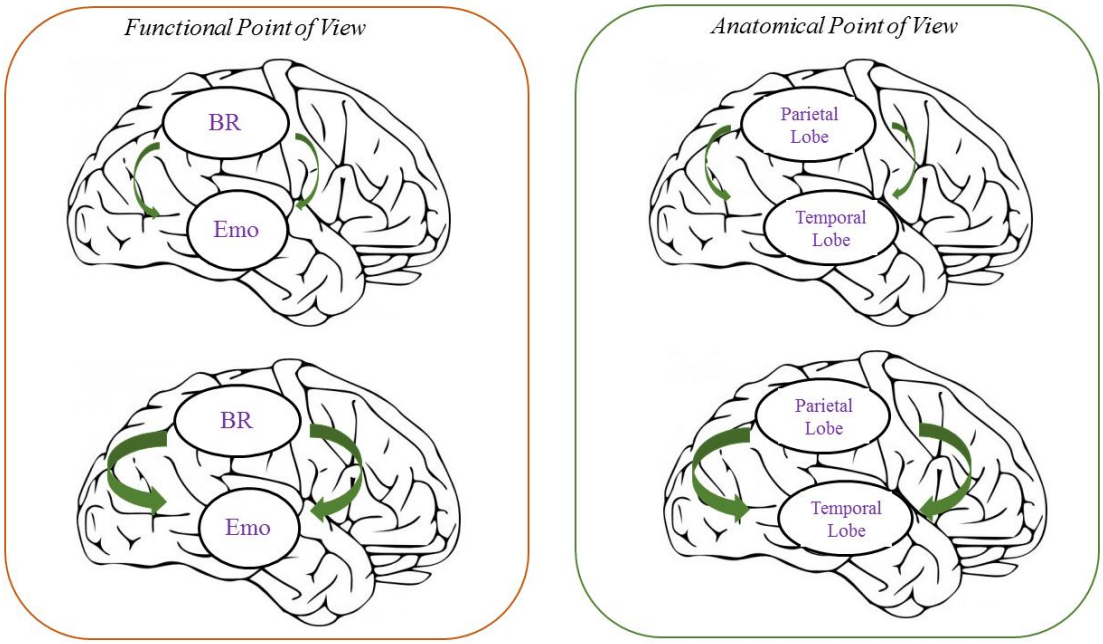


Fig. 2

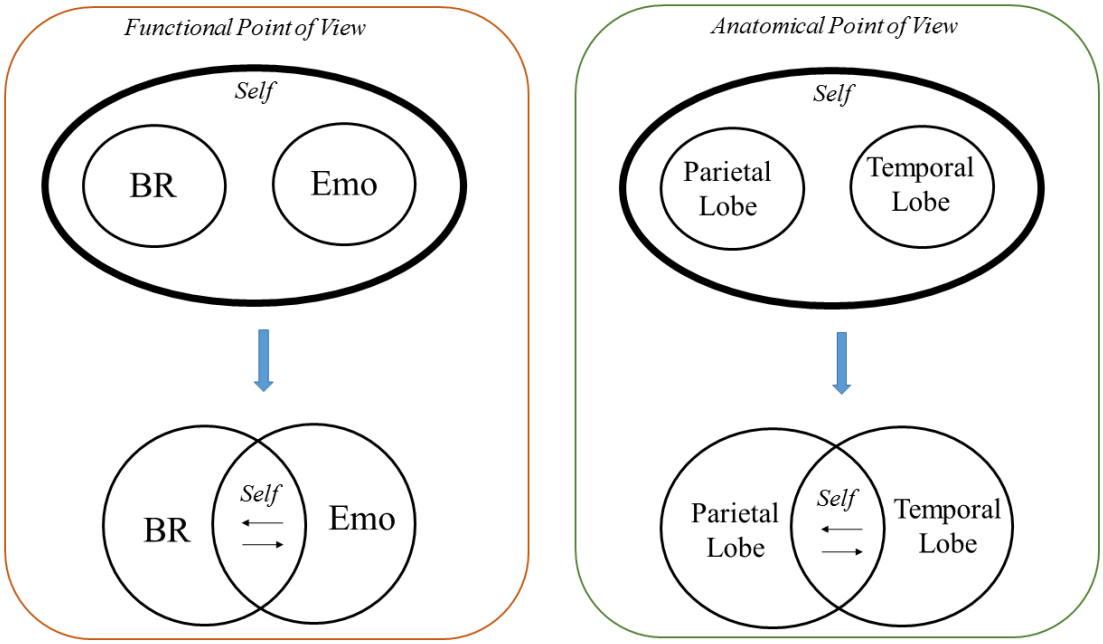
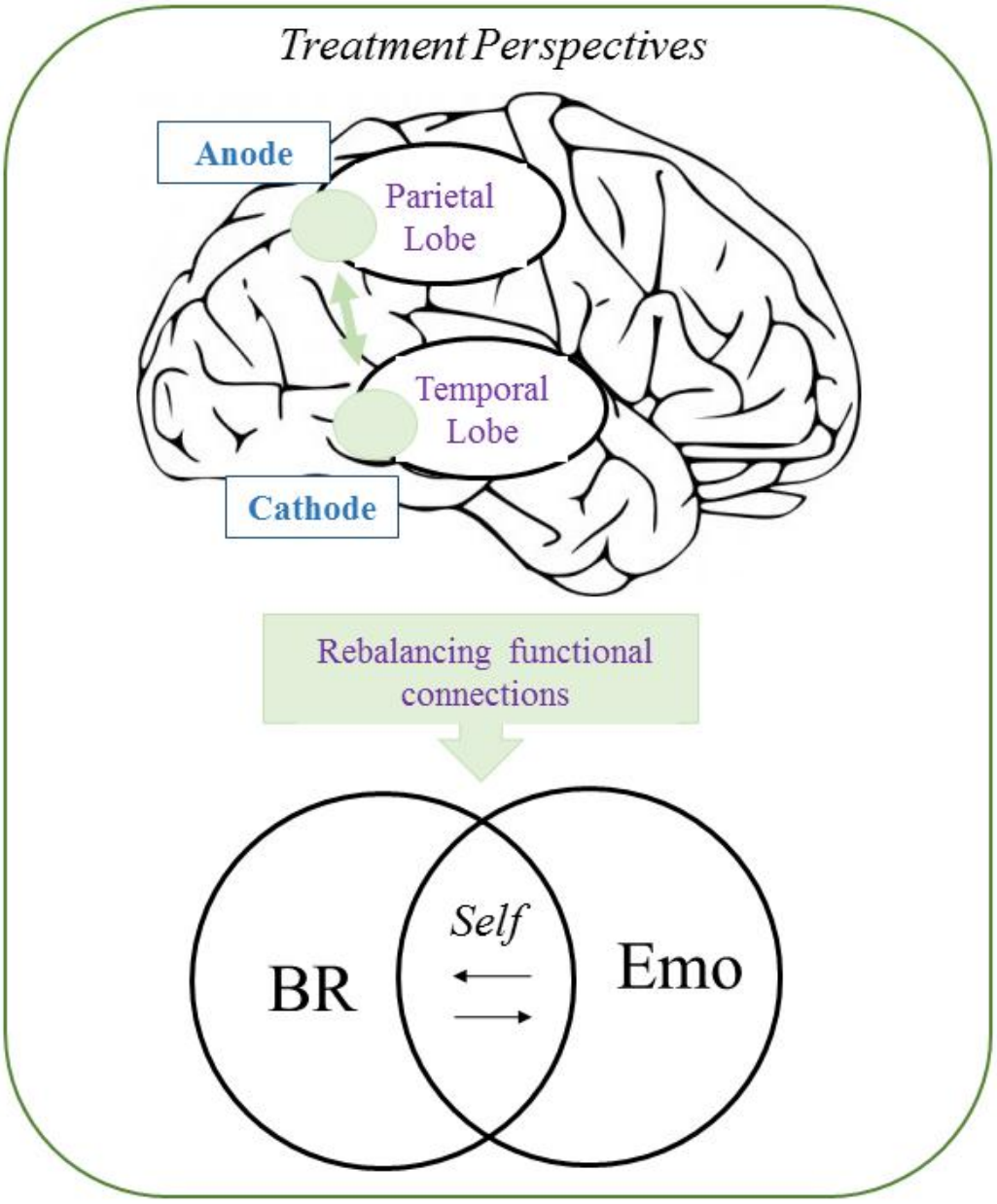


Fig. 3



	Authors	Year	Population	Function Explored	
				BR	Emo
Psychiatric	Mussgay et al. [30]	1999	Patients with psychosomatic disorder	X	X
	Müller et al. [31]	2015	Patients with Borderline Personality Disorder	X	X
	Pollatos et al. [32]	2008	Female patients with anorexia nervosa	X	X
	Mantovani et al. [33]	2011	Patients with Depersonalisation Derealisation disorder		X
	Terhaar et al. [34]	2012	Patients with depression	X	X
	Hart et al. [35]	2013	Patients with Borderline Personality Disorder	X	X
	Michal et al. [36]	2014	Patients with Depersonalisation Derealisation disorder	X	X
Neuropsychological	Critchley [37]	1974	Patients with misoplegia	X	X
	McIntosh et al. [38]	2000	Neglect patients	X	
	Lindell et al. [39]	2007	Patients with unilateral stroke in right hemisphere	X	
	Heydrich & Blanke [40]	2013	Patients with autoscopy	X	X
	Pollak et al. [41]	2003	Patients with vestibular dysfunction (vertigo)		X
	Godemann et al. [42]	2004	Patients with vestibular neuronitis		X
	Sang et al. [43]	2006	Patient with peripheral vestibular disease		X